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GENERIC THERMO-MECHANICAL MODEL FOR JOINTED ROCK MASSES

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ABSTRACT A new nonlinear thermo-mechanical model for heavily jointed rock masses is presented. The model uses correlation functions between the porosity and the basic rock properties such as elastic moduli, tensile and compressive strength. The model assumes that the media is isotropic and is characterized by two variable parameters: insipient porosity and in-situ-to-intact modulus ratio.

INTRODUCTION: The objective of this paper is to develop a methodology to model nonlinear response for *in situ* rock masses. The i*n situ* model is build as an extension of the model for intact rock samples [Vorobiev, Liu et al 2007] with the strength properties scaled down according to the Hoek-Brown empirical rule [Hoek & Brown 1998] using GSI index characterizing the rock mass quality. Continuum model has been compared with explicitly modeled jointed media. The joints were modeled using advanced contact detection described in [Vorobiev 2007].

MODEL EXTENSION FOR INSITU ROCKS: It is known that the compressibility and the strength of limestones depend on the insipient porosity of rock samples [Vajdova 2004]. Figures 1,2 below show porosity correlations for the crush pressure and the initial bulk modulus.

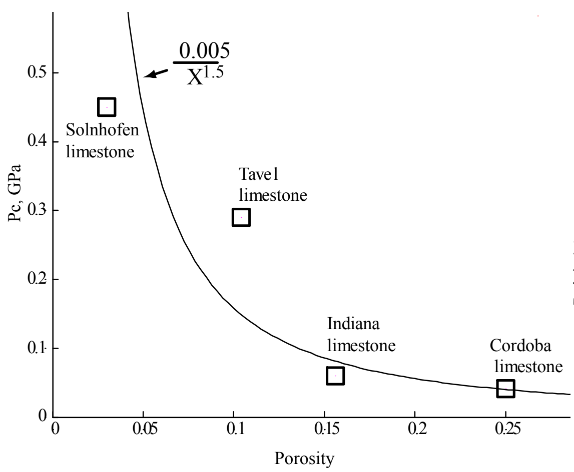

Fig.1. Correlation between the porosity and the crush pressure for the limestones

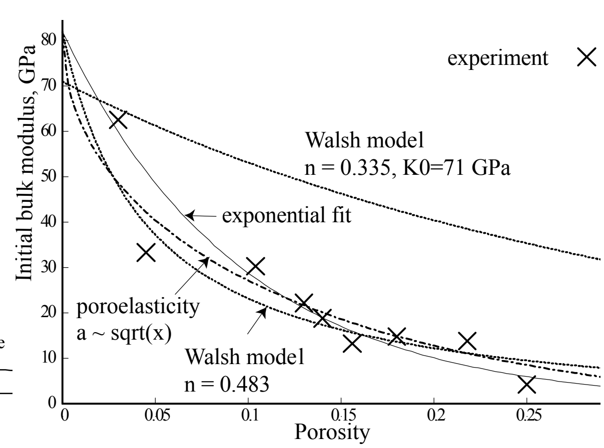

Fig.2. Correlation between the porosity and the initial bulk modulus the limestones

The correlation functions are used in the model for the intact rock instead of constant parameters. The presents of joints makes the rock weaker. Using in-situ-to-intact modulus ratio, F, the scale factor for the unconfined compressive strength, s, can be found by Hoek-Brown empirical rule as $s = F^4$. The initial bulk modulus for the *in situ* rock is matched by enhancing poroelaticity parameters to satisfy the given modulus ratio.

COMPARISON WITH THE EXPLICITLY MODELLED JOINTED ROCK: The results of simulations of quasi-static uniaxial strain loading of a jointed rock in horizontal direction calculated with an explicit 2D Lagrangian code are given in Fig.3. Assuming a linear response of the solid and nonlinear hyperbolic stiffening of the joints gives the following relationship between the axial stress, T_A, and the axial strain, ε_A:

$$T_A = \frac{1}{2}E_s\left[\sqrt{\left(\frac{E_j}{E_s}+\frac{a}{d}-\left(1+\frac{a}{d}\right)\varepsilon_A\right)^2+4\frac{E_j}{E_s}\left(1+\frac{a}{d}\right)\varepsilon_A}-\frac{E_j}{E_s}-\frac{a}{d}+\left(1+\frac{a}{d}\right)\varepsilon_A\right] \qquad (1)$$

The joint model and the numerical method are described in [Vorobiev 2007]. It follows from the analytic solution that the effective initial modulus of the jointed rock with vertical joints, E_{eff}, can be expressed using joint and solid moduli, E_j and E_s, as

$$E_{eff} = \left(\frac{\partial T_A}{\partial \varepsilon_A}\right)_{\varepsilon_A \to 0} = E_s E_j\left(\frac{d+a}{E_j d + E_s a}\right) \qquad (2)$$

where a is the maximum joint closure (the aperture) and d is the joint spacing.

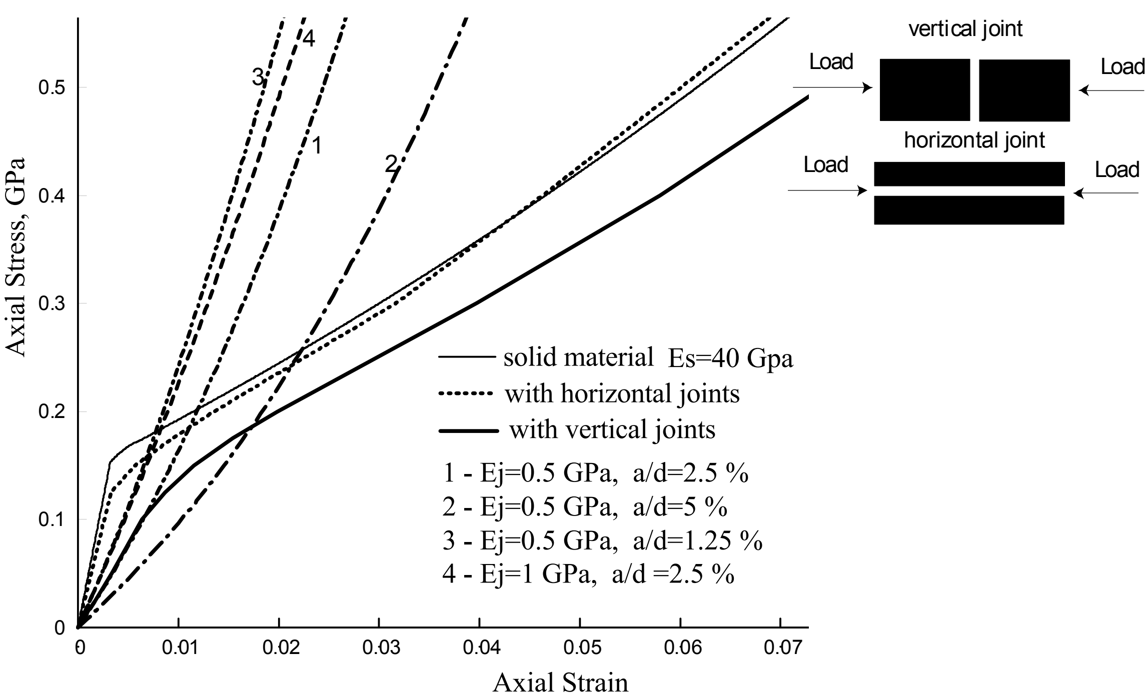

Fig.3. Uniaxial loading of solid and jointed limestone. Curve 1 is the analytical solution without porous compaction for the given joint density. Analytical solutions 2, 3 and 4 show sensitivity to various E_j and *a/d* values.

Numerical results calculated for the vertical joints (Fig.3 solid line) agree with the analytical prediction for the initial part of the loading (line 1). Porous compaction changes material stiffness at high strains. This is not accounted for by the analytical model. The two cases of joint orientation considered above (the vertical and the horizontal) do not represent the general case of randomly oriented joints. More general cases which require intensive 3D simulations are currently under way. By modeling the effective compressibility and the strength of the jointed rock at the same time one can find the limitations of the Hoek-Brown approach. Another goal of this study is to relate the scaling factor, s and the effective elastic properties of the rock mass, E_{eff} , to the properties of the joints.

CONCLUSIONS: The new parametrized model has been designed for large scale simulations involving rock masses with variable porosity fields and variable GSI index. It is assumed that joints are randomly oriented and the yield surface for the *in situ* material is found as a scaled yield surface for the intact material. As an alternative to the Hoek-Brown scaling the effective properties of heavily jointed rocks can be found numerically in explicit calculations if both the joint and the solid responses are known.

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